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THE USE OF SIMULATION IN MANAGEMENT ANALYSIS -- A SURVEY AND BIBLIOGRAPHY

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(ABSTRACT)

THE USE OF SIMULATION IN MANAGEMENT ANALYSIS A SURVEY AND BIBLIOGRAPHY

by D. G. Malcolm

Computer Simulation, or System Simulation, is being used in research and design for seeking a better understanding and control of business operations. Three concurrent developments account for the emergence of simulation as a management analysis method: the need for more detailed and accurate analyses in the competitive business world, the development of new engineering analysis methods, and the availability of high-speed electronic computers.

Typical simulation projects directed to the following objectives are discussed: Systems Design and Evaluation, Systems Research and Planning, and Training (both Appreciation and Procedural). In the ideas involved lie the possibility for a new management control concept. It seems likely that management may someday be provided with a computer model of the business -- one permitting experimentation with policy and procedure changes as well as evaluation of alternative plans. A bibliography of publications on Simulation, Gaming is included.

THE USE OF SIMULATION IN MANAGEMENT ANALYSIS

A SURVEY AND BIBLIOGRAPHY[1]

The role of the modern industrial manager is indeed a complex, perplexing one. For, operating in the face of uncertainty in our dynamic, competitive, non-linear and probabilistic world, he is called upon to make major innovations and to adjudicate the proposals for change that come from the various functions or divisions of his total organization. This problem of obtaining economic balance, or least-total-cost operation as it may also be phrased, today, as well as in the plans for future operations, is most important to the success of his company. The need for such balance promises to become even greater in future years as we learn better to use the information handling and decision-making apparatus made possible through electronic computers. As many writers have indicated, such successful use of computers may be a necessary ingredient to corporate survival.

Computer Simulation, or System Simulation, is proving to be a useful tool in this quest for better understanding and control of business operations. It is our purpose here to explore briefly what simulation is, who is doing it, for what purpose, and to speculate on its future outlook.

In this discussion, we shall define a simulation project as one which depicts the workings of a large-scale system of men, machines, material and information operating over a period of time in a simulated environment representative of the actual real world conditions. A simulation project generally utilizes an electronic computer and may operate in "real" time or in compressed time where the simulated system may be operated for several years in but a few hours of computer time.

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[1] A revised edition of this bibliography will appear in a forthcoming issue of Operations Research

In effect, the arrival of simulation on the management analysis scene is dependent on three concurrent developments. We have already touched on the first and perhaps most important, the need and desire on the part of management to have a more complete and accurate analysis of alternate courses of action and to obtain economic balance in operations. Little more needs to be said here concerning this point.

The second development stems from the use of engineering systems analysis, and/or operations analysis in this management area. Operations Researchers have found that the number of variables, the probabilistic aspects and the servo aspects of systems under study often defy the use of strictly analytical or mathematical methods of analysis.[2] Simulation of the system or process under study often permits sufficient alternatives to be evaluated, thus leading to a better, if not optimum, solution.

The third development making the use of simulation a practical tool is the advent of the high speed electronic computer. Our discussion will be confined to the use of digital computers since they have been found, by and large, most applicable to the class of problems involved.

Since it has often been predicted that computers will become automatic decision-making devices and indeed many have been purchased with this stimulating and challenging goal in mind, it is well to spend a few paragraphs in describing the current state

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[2] Ricciardi, Craft, Malcolm, Bellman, et al., Top Management Decision Simulation, American Management Association, 1957.

Thomas, Clayton J. and Walter L. Deemer, Jr., "The Role of Operational Gaming in Operations Research," Operations Research, February, 1957.

and categories of usage of computers in industry. In this way, the role of simulation can be put in better perspective and the specter of technological unemployment amongst decision makers (if it exists) can be dispelled.

I. CATEGORIES OF USES OF COMPUTERS IN THE MANAGEMENT PROCESS

In making this categorization, we are delimiting our scope from the scientific and physical engineering applications of computers to those applications more generally thought of as involving and directly assisting the management of the organization. This area of application we have termed the "management process". Here, there are three major categories of uses to which computers have been put.

(1) A Data-Processing Tool

(2) A Problem-Solving Tool

(3) A Controlling Device

1. A DATA-PROCESSING TOOL

Since the first installation of an electronic computer for strictly business use at General Electric in Louisville in January 1954, there has been a mushroom-like growth in the application of computers to the routine automation of existing information, communication, personnel, and other data reporting systems. This includes such applications as payroll, inventory position and control, production release and invoicing systems, etc. Of the $631 million of computers to be installed by June 1959, and the $591

million on order, it has been estimated that up to 90% of machine time will be used for applications in this category.

It should be pointed out that most of these systems which are being automated, are not being evaluated in the sense that their ability to best perform the function for which they were designed is itself critically examined. Most installations are undertaken for the purpose of reducing time in report preparation or in the attempt to effect clerical savings.

2. A PROBLEM-SOLVING TOOL

The computer is often used as the vehicle for research in connection with the design of management control systems, for policy determination and for training purposes.

There is a considerable amount of simulation activity in connection with such problem solving and it will be the subject of this paper to survey some of these uses. Generally speaking simulation projects are directed to one of the following objectives:

(1) System Design and Evaluation

(2) System Research and Planning

(3) Training - Appreciation, procedural or study display

Successful development in these areas will lead to the third major category of computer usage.

3. A CONTROLLING DEVICE

Currently, only exploratory pioneering work is being done in using the computer directly in management decision making. In this category of usage

we may visualize the computer as an "on-line" or "in-line" controller--operating on information received concerning sales, production, changes in environment, etc.--to make decisions on personnel requirements, schedules for production, inventory pricing, etc., on a day-to-day basis.

To be effective, such usage involves the building of adequate decision-making criteria into a computer model of the company or of a component of it. The challenge facing the would-be designer, of what is referred to as a "truly integrated system", is to:

(1) Program a computer to become, as appropriately as possible, an on-line controller and,

(2) Make the computer an effective instrument for experimenting with, and evaluating the effectiveness of, proposed changes in policies, procedures and plans.

While such automatic decision making (at the level of the firm) is still a long way off, significant strides are being make in some of the components and subcomponents of the business. Some of the simulation projects under the category of "Systems Design and Evaluation" performed in components of the business are clearly the forerunners of this new management control concept. One can gain much insight into the nature of future management control systems through study and examination of such projects.

II. PURPOSES IN THE USE OF SIMULATION

Simulation has long been used as an engineering method in the study and design of mechanisms and controlling apparatus.[3] Its extension to the managerial world has been for three major purposes.

(1) To study complex operating plans and management controlling systems for the purpose of designing better plans and/or systems.

(2) To study and train people in the operation of complex tasks generally involving machines or instruments. Study of that old bugaboo - human interaction - is a major purpose in the use of simulation.

(3) To present proposed changes in such a way that enhances acceptance of change through better understanding of how a given system works or operates. In this way the costly job of installation may be significantly reduced.

In this discussion, a control system will be defined as a machine and set of procedures which directs, monitors, (i.e., controls) an operation. An operation is defined as an organization of men, machines and information working toward a stated objective. There are several hierarchies of control

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[3] Hawkins, G. A., and L. M. K. Boelter, "The General Mode of Analysis in Engineering Education", The Journal of Engineering Education, January 1954.

Goode, H. H., "Simulation - Its Place in System Design", Proceedings IRE Vol. 39, 1951.

systems and they may take different form in regard to their treatment of inputs and outputs. For example, a control system may have some automatic inputs and some manual inputs. It may have automatic outputs that provide closed loop inputs, or it may have manual outputs or displays for human monitoring.

III. TYPES OF SIMULATION

It is useful to further categorize simulation in regard to the presence or absence of competition in the basic model. A situation, under study, involving the interactions of individuals, companies or countries competing toward common, interrelated goals may be referred to as Competitive Simulation. Where the system, be it man or organization, is being studied in a changing environment or with changed system parameters - the term System Simulation may be applied. Examples of each may be found in the tabulation in the following section.

IV. THE USE OF SIMULATION IN TRAINING

Man has used simulating devices for many years to train people in the operation of new machines or equipment where training with the real equipment in real environment is either too costly or dangerous. In this discussion, which is primarily directed to use of simulation in management analysis, we shall pause only briefly to indicate that simulated situations often involving the use of a computer have been set up to provide training to individuals in

the operation of management controlling systems or to provide simulated experience in decision making. A moment's consideration will bring out the importance of this point. We thrust the newly created manager into the role of operating a large organization without providing him with an opportunity to be trained in or to experiment with this most costly control apparatus. Simulation exercises have been designed to provide the executive trainee with an appropriate amount of synthetic experience in decision making.

These range from simple exercises such as General Electric and Westinghouse have created to train distribution managers in the reorder rules in inventory control to the top management decision exercises of AMA,[4] IBM and UCLA. The following is a partial listing of some simulation training exercises. (A more complete listing of such exercises may be found in the attached bibliography under "Games - Industrial".)

ORGANIZATION	TYPE OF SIMULATION	PROBLEM AREA	COMPUTER
American Management Association and Booz, Allen and Hamilton	Competitive	Top Management Decision	Medium
General Electric	System	Distribution Inventory	None
IBM	Competitive	Marketing Mgmt. Decision	Medium

[4] Bellman, Richard, C. E. Clark, D. G. Malcolm, C. J. Craft and F. M. Ricciardi, "On the Construction of a Multi-Stage, Multi-Person Business Game", Operations Research, August, 1957.

ORGANIZATION	TYPE OF SIMULATION	PROBLEM AREA	COMPUTER
RAND	System	Logistics System Training	Large
		Monopologs	None
System Development Corporation	System	Air Defense System Training	SAGE
UCLA	Competitive	Top Management Decision	Medium
	System	Engineering Economy Classes	Small
Westinghouse Electric	System	Distribution Inventory	None

In passing it is interesting to summarize the advantages claimed in using simulation in the management training area.

(1) Permits "cause" and "effect" to be felt.

(2) Aids student in evaluating available information.

(3) Familiarizes individual with data needed.

(4) Through "involvement", creates high motivation in student.

(5) Provides familiarity with Electronic Data Processing.

V. INDUSTRIAL USES OF SIMULATION IN SYSTEMS DESIGN AND EVALUATION

Simulation is useful in the study of a class of problems wherein the operating rules, policies, procedures, and other elements that control production, inventory, etc., are under question. One should like to employ practices that are the best and produce the smoothest, lowest cost operation. The number of variables involved, the uncertain nature of inputs, among other things, make these problems, which are referred to generally as a system, difficult to analyze. A brief review of a few such projects will serve to illustrate the nature of the model and analysis.

1. MAN-MACHINE PRODUCTION OPERATION

Eastman Kodak has simulated their roll-film spooling operation using Monte Carlo methods on their 705 computer. Conditions change continuously in regard to this operation, both in the mix of size and run of individual products as well as in the maintenance requirements and equipment design. Simulation has been quite useful as the standard means for:

(1) Equipment redesign

(2) Organization of the operating crew procedures

(3) Maintenance and operating crew size determination

The model has permitted control methods to be developed so that better decisions can be made in the light of continuously changing conditions. This is but one of several simulations made by the Industrial Engineering Division.

2. PRODUCTION CONTROL MODEL

The General Electric Company is using simulation to test new concepts and methods in production scheduling. Every production control manager knows that the methods, priority rules and procedures that he uses in discharging his scheduling job have an important effect on his company's utilization of men and machines and also upon how smoothly the production flows and serves the customer.

In this model, factory operations are simulated to test these decision rules which, in effect, are the scheduling system. Policies and procedures concerning machine loading, scheduling, and dispatching are being systematically tested in the laboratory and evaluated in terms of internal inventory cost, idle man and machine time and flexibility and cost of the scheduling itself. In this way the trial and error method of actually trying out a new approach will be avoided. Rowe and Jackson have discussed this problem of research.[5]

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[5] Rowe, A. J., "Computer Simulation Applied to Job Shop Scheduling", Report of System Simulation Symposium, Co-Sponsored by AIIE, ORSA, TIMS, Feb. 1958.

Rowe, A. J. and J. R. Jackson, "Research Problems in Production Routing and Scheduling", The Journal of Industrial Engineering, May-June 1956.

3. DISTRIBUTION AND INVENTORY CONTROL MODEL

Imperial Oil has studied an extensive distribution system composed of many hundreds of field warehouses in connection with an extensive expansion problem. The flow of stock under various possible combinations of facility plans was studied by simulation and costed. Results of this work were instrumental in determining the feasibility of a central warehousing method of operations.

Inventory and distribution problems are particularly complex and interrelated and are among the most important problems in management today. It is understandable, therefore, that we find considerable activity in the simulation of various distribution and inventory problems. Several papers in addition to the above, were presented at a recent symposium on system simulation which dealt with this subject.[6]

4. PROFIT PLANNING SIMULATION

A television tube manufacturing company has explored ways of obtaining better profit from its over-all operations through simulation.[6] The flow of product was studied throughout the entire system. A flow chart of material from the point of purchase through operations in manufacturing to transportation in the distribution system was made. This chart served as the basis for programming a computer. Such factors as changes in volume imposed by the changes in customer demand, changes in product mix from a scheduling point of

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[6] Report of System Simulation Symposium, Co-Sponsored by AIIE, ORSA, and TIMS, Feb. 1958.

view, changes in the method and pattern of distribution and storage, changes in the number and location of manufacturing plants and different expected losses of product in the manufacturing process could be made in the program put into the computer.

By studying these changes, it was possible to find out which factors were of the greatest sensitivity in producing profit and it was possible to experiment with possible changes in any of the factors indicated. Finally, the company feels that it has a realistic mechanism for planning and controlling its business system.

The following is a listing of several simulation projects of the same general nature as those reported above and the bibliography on simulation at the end of the paper lists additional articles of interest.

SIMULATION IN SYSTEMS DESIGN AND EVALUATION

ORGANIZATION	SYSTEM SIMULATED	SIZE COMPUTER
Atlantic Refining	Inventory & Transportation of Casing	Medium
Eastman Kodak	Roll-Film Spooling Operation	Large
	In-Process Inventory	Large
	Elevator Systems, Plant Layout Study	Large
	Production Scheduling	Large
	Supply System	Large
General Electric	Job Shop Scheduling	Large
	Profit Planning Simulation	Medium
Humble Oil	Oil Tanker Scheduling	

ORGANIZATION	SYSTEM SIMULATED	SIZE COMPUTER
Imperial Oil	Distribution System	Medium
Operations Research Office, The Johns Hopkins University	OM - Requirement Forecasting	Large
Port of New York Authority	Design of Bus Terminal	Medium
RAND	Air Force Logistics System	Large
Thompson Products	Inventory Control	Large
United Air Lines	Customer Servicing	Medium
United Steel Cos. Ltd.	Steelworks Flow Problems	Special

VI. THE USE OF SIMULATION IN SYSTEMS RESEARCH AND PLANNING

Projects in this area differ from the above largely in the fact that they are oriented more towards the future time frame and may consider the effect of equipment not yet designed. One of the distinct problems in evaluating the effect of introducing a technological change into an operating system is the subtle effect it may produce on operating costs. Lowering costs in one area often raises costs in other areas. The immense and time consuming job of assessing these costs has often precluded the systematic study of alternatives. Computer Simulation can often be used as a means of determining Total Systems Costs for the change under study. Total system costs provides the most realistic basis for comparing alternative plans. Two excellent examples of such an application are:

1. NUCLEAR SHIP EVALUATION MODEL[7]

This problem, solved by Matson Navigation, compared ships of different sizes, speeds and power plants in addition to the proposed nuclear vessel whose design parameters were also to be determined. The problem was to determine where such a vessel might fit in the fleet of vessels serving a known cargo transportation pattern. A series of expected voyages representing more than a year of operations for the fleet was simulated. The cost and performance characteristics of each ship were entered into the computer and the fleet was operated according to predetermined assignment rules. The computer was programmed to keep track of costs, revenue, etc., and permitted evaluation to be made of different operational plans, different nuclear vessel design parameters and different mixes of types of ships.

2. AIRPORT STATION MODEL[8]

United Air Lines has set up and operated a simulation of the operations at a large airport on an IBM 704 computer. Several months of actual operations at an air terminal can be simulated in a matter of minutes. If one visualizes the "flow" of a plane through an airport and all the factors that determine the total time spent, such as landing, taxiing, maintenance, loading, etc., an idea of the

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[7]Graham, F. B., "Determining the Comparative Economics of Nuclear Propulsion", Recent Research in Maritime Transportation, Publication 592, National Academy of Sciences - National Research Council, Washington, 1958.

[8]Alberts, W. E., "Systems Simulation", Proceedings of the Seventh Annual National Conference, AIIE, May 17-18, 1956.

complexity of the simulation is afforded. There are reportedly some 9,000 instructions in the computer program which took some nine months to develop after the logic was worked out in flow form.

This model involved such structural and environmental elements as:

Time of day, week, and year

Weather conditions

Maintenance plan

Availability of spare aircraft

Manpower schedule

Probabilistic factors such as the need for maintenance, the type and length of resulting repairs, absenteeism of personnel and scheduling delays form the variable background for testing changes in company policies and practices. For example, management can change the number of spare aircraft, or the manpower schedule, and simulate operations under these new conditions. The computer is programmed to provide such output measures of performance as expected idle manpower, expected idle equipment, utilization of maintenance and berthing facilities. By comparing the expected performance in terms of these outputs with the cost of obtaining that performance, decisions can be reached that produce the best over-all performance of the complex airport system.

Simulation projects of a similar nature are listed below.

SIMULATION IN SYSTEMS RESEARCH AND PLANNING

ORGANIZATION	PROBLEM AREA	COMPUTER
Air Materiel Command	Aircraft Engine Management Model	None
Cal-Texas Oil Company	Group Operations Decision Model	None
Operations Research Office, The Johns Hopkins University	Army Battalion Tactical Maintenance	Large

VII. RESEARCH AT UNIVERSITIES AND GOVERNMENT AGENCIES

Any comprehensive discussion of research in this area would be prohibitive in length. Suffice it to say that the simulation approach is proving quite useful to the basic researcher in more adequately describing problems of a dynamic nature. The simulation approach has proved a useful tool in conserving our scarce mathematical talents. Often laying out the problem in this manner gives sufficient structure to the problem to challenge the talents of creative mathematicians who otherwise might not be sufficiently convinced that there was a problem requiring their talents.

The following listing is offered as being indicative of the types of simulation projects underway.

ORGANIZATION	PROBLEM AREA
Canadian Defense Research Board	Operations in Mining Cycle
George Washington University	Tanker Design
MCTC	Port Operations
M.I.T.	Inventory Control Model Vehicular Traffic
Stanford	Evaluation of Quality Control Plans
Tufts	Production Scheduling
U.C.L.A.	Cargo Handling Containerization Warehouse Layout

VIII. PROBLEMS IN USE OF SIMULATION

Perhaps the most dramatic aspects of system simulation lie in its ability to reproduce the workings of large scale systems. While such ambitious programs are of great interest, it should be borne in mind that their success is dependent on having performed many smaller simulations for experience, upon adequate input data and upon consideration of the many mathematical and statistical problems that are involved in the construction of a sueful model. Those considering broad full-scale models as panaceas in the management analysis and decision-making areas are well advised to engage in smaller projects at the outset. This will prevent certain disillusionment and make for a more meaningful research program.

Following this vein, perhaps a listing of some of the more common problems to be encountered in the use of simulation will be useful to the potential user.

(1) Broad problems generally require the use of a computer. This can be costly both from a programming as well as an operating point of view. For example, one of the large-scale simulations referred to took over two years to become operational.

(2) Development of considerable new data is generally necessary. The input distributions required in simulations cannot generally be derived from existing data sources and surveys. Quite often experiments must be designed to obtain the necessary data. While costly, this data collection generally develops other information and insights of great value.

(3) Very large problems are often unwieldy and hard to program. The interrelationship of factors in the model adds considerably to the complexity.

(4) In large problems, the task of exploring all the possibilities of parameter changes creates a volume of calculations that may swamp the analyst. Consideration should be given to analysis before designing the simulation.

(5) Comparison of simulation runs, as well as their length, pose statistical problems requiring the presence of an experienced mathematical statistician.

(6) The effect of the accuracy of input data should be explored. Analysis of outputs of a simulation based on input data of unknown or questionable inputs is difficult.

(7) And finally, in their enthusiasm for this method many analysts have discovered that simpler methods of analysis may exist. It is well to search for such methods early in the task of problem solving.

IX. THE FUTURE OUTLOOK

It seems clear that modern management is driving continuously toward a better understanding of the "process" for which it is responsible. In this search for more precise definition concerning what is controllable and what is uncontrollable, it is quite evident that simulation modeling will be a necessary research approach. As the answers unfold we shall gradually see develop a new management control concept based on precepts discovered in the operation of the research models.

In the future it does not seem at all unlikely that management will have a computer model of its business, rich enough in detail and comprehensive enough in scope to permit experimentation with suggested policy change. Further, the model may well be able to administer policy more adequately and consistently than the human administrator. The decision maker will then be freed for the more important task, that of understanding the limitations of the model and in searching imaginatively for beneficial innovation.

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Included in this partial bibliography are publications in the general area of System Simulation, Operational Gaming, Games, War Games, some selected references in Game Theory and Related Research. This is not intended to represent a complete listing of publications. The bibliography is organized as follows:

Simulation

- Industrial
- Military

Games

- Industrial
- Military

Game Theory

Related Research

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DESCRIPTORS: Simulation. Industrial
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Reports that computer simulation, or
system simulation is being used in
research and design for seeking a better UNCLASSIFIED

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understanding and control of business UNCLASSIFIED
operations. Discusses typical
simulation projects directed to the
following objectives: Systems Design and
Evaluation, Systems Research and Planning,
and Training (both Appreciation and Procedural).
Reports that management may some day be provided
with a computer model of the business -- one
permitting experimentation with policy and
procedure changes as well as evaluation of
alternative plans. The bibliography of
publications on Simulation and Gaming
contained in this document has been
superseded by SP-126 (Bibliography on the
Use of Simulation in Management Analysis by
D. G. Malcolm, 10 November 1959). UNCLASSIFIED